Effect of Thermal Relaxation on LSP Induced Residual Stresses and Fatigue Life Enhancement of AISI 316L stainless steel

M. Díaz, L. Ruiz de Lara, J.A. Porro, C. Correa and J.L. Ocaña

Centro Láser UPM. Universidad Politécnica de Madrid

Campus Sur UPM. Edificio La Arboleda.
Ctra. de Valencia, km. 7,300. 28031 Madrid. SPAIN
Tel.: (+34) 913363099. Fax: (+34) 913365534.
email: jlocana@etsii.upm.es

4th International Conference on Laser Peening and Related Phenomena
May 6th-10th 2013
ETS de Ingenieros Industriales, Universidad Politécnica de Madrid, SPAIN

4th International Conference on Laser Peening and Related Phenomena
May 6th-10th 2013
ETS de Ingenieros Industriales, Universidad Politécnica de Madrid, SPAIN

OUTLINE:

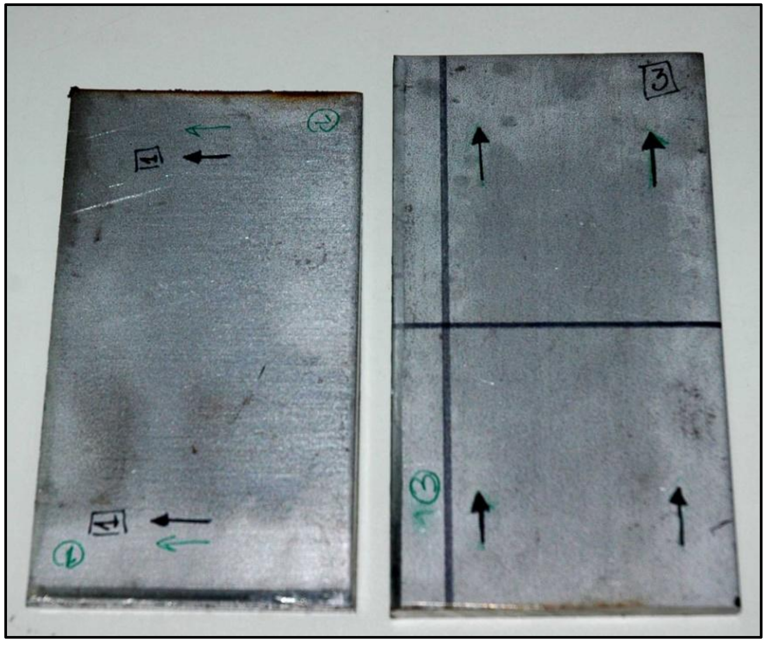
- **Motivation**
- **As-recieved material characterization**
  - Chemical composition
  - Microstructural analysis
  - Mechanical properties
- **Experimental Procedure**
  - LSP parameters and annealing conditions
  - Surface roughness measurement
  - Residual stresses measurement
  - Fatigue test
- **Experimental results**
  - Residual stresses
  - Fatigue Life Tests
- **Concluding remarks**

1. MOTIVATION

- The enhance of fatigue resistance of metallic components due to the presence of near-surface compressive residual stresses by laser peening has been widely demonstrated.
- Many metallic parts used in industrial applications are subjected to cyclic loadings , high temperatures or both of them simultaneously.
- From a practical point of view, it is important to study the stability of the residual stresses induced by laser peening, as well as the fatigue life of the material, under high temperature conditions.
- In the present communication, the level of relaxation of the residual stresses induced by laser peening in stainless steel 316L after a thermal treatment, and its fatigue performance before and after the thermal treatment is presented.

2. MATERIAL CHARACTERIZATION

Hot-rolled plates of stainless steel 316L
Thickness: 6 mm

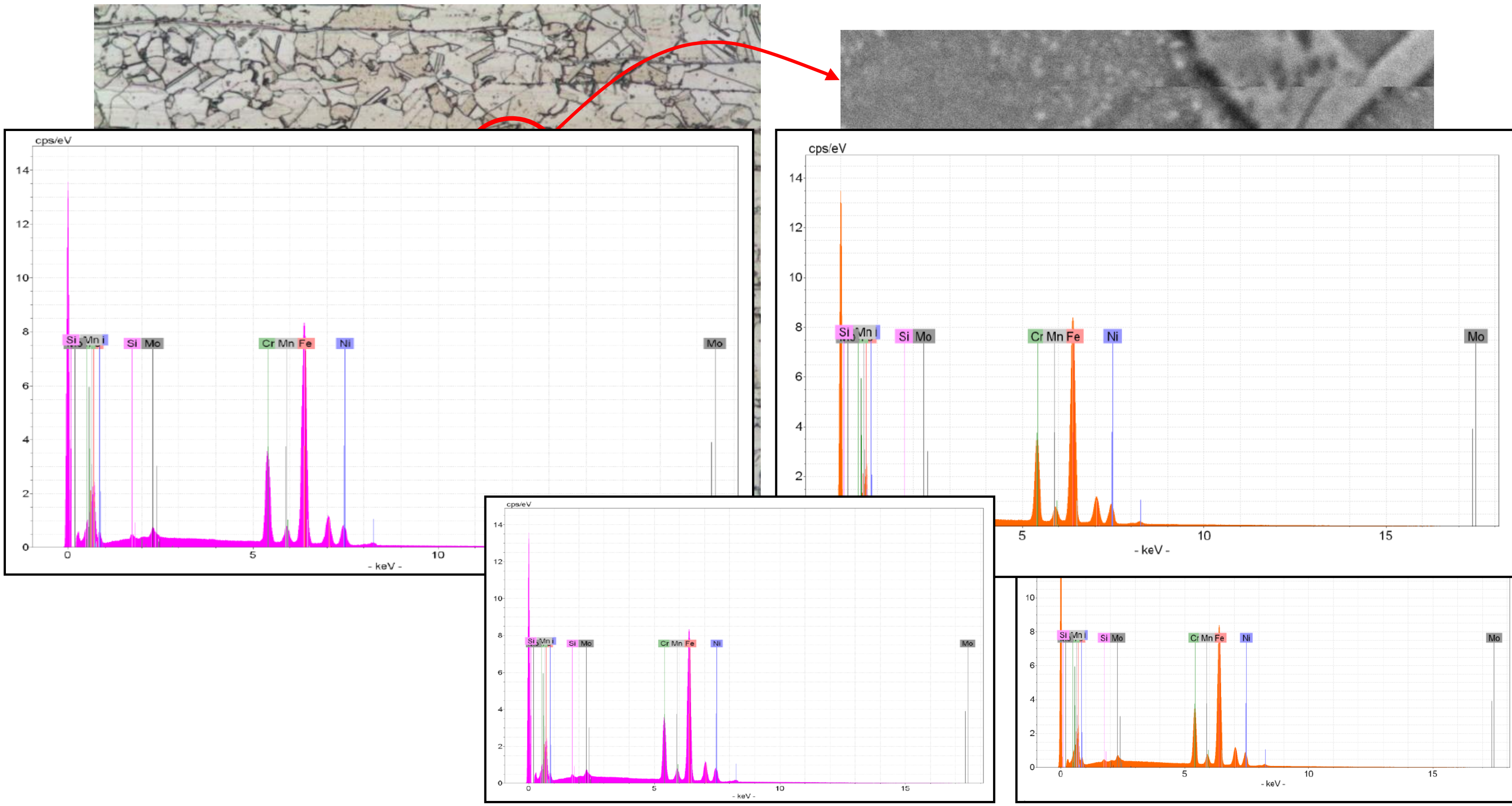


Chemical composition AISI 316L stainless steel (%)									
Casting	C	Cr	Mn	Mo	N	Ni	P	S	Si
T7C9	0.018	16.46	1.90	2.34	0.047	9.78	0.032	0.003	0.26

*Balance Fe (69.203%)

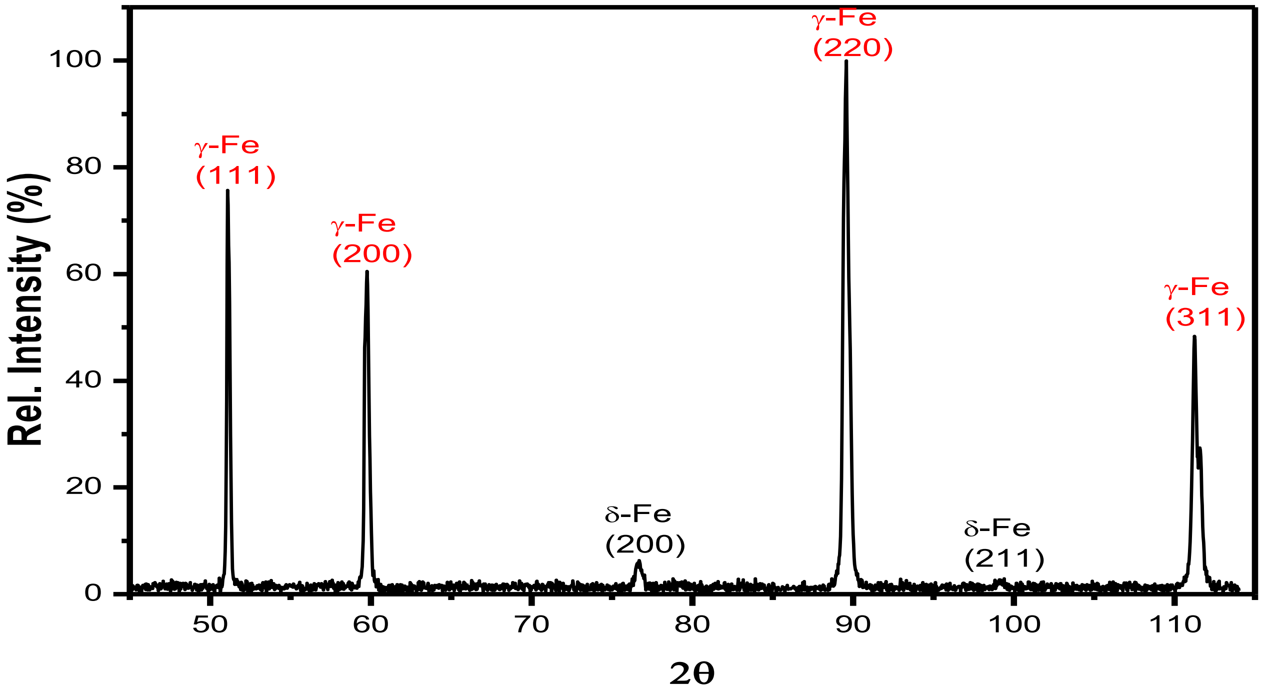
2. MATERIAL CHARACTERIZATION

- **Microestructural analysis**
  - Optical microscopy
  - SEM



2. MATERIAL CHARACTERIZATION

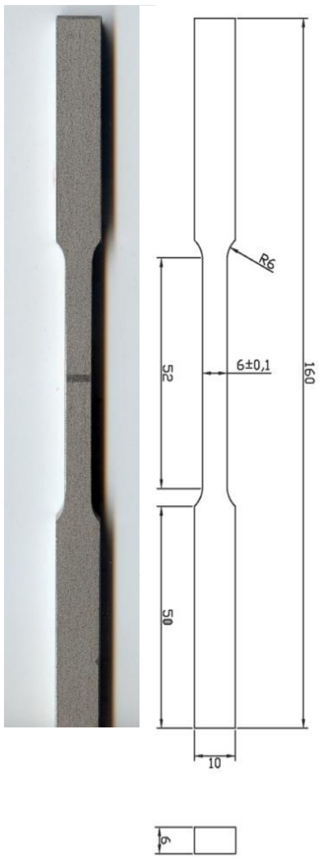
- **Microestructural analysis**
  - DRX

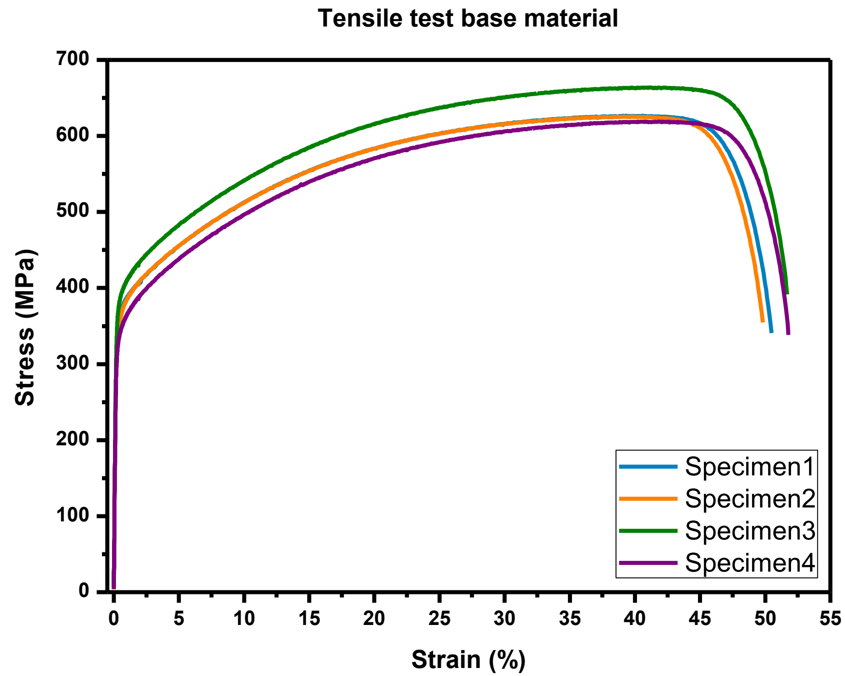


3.5 wt% of δ-ferrite (from Rietveld refinement)

2. MATERIAL CHARACTERIZATION

- **Mechanical properties**
  - Tensile test

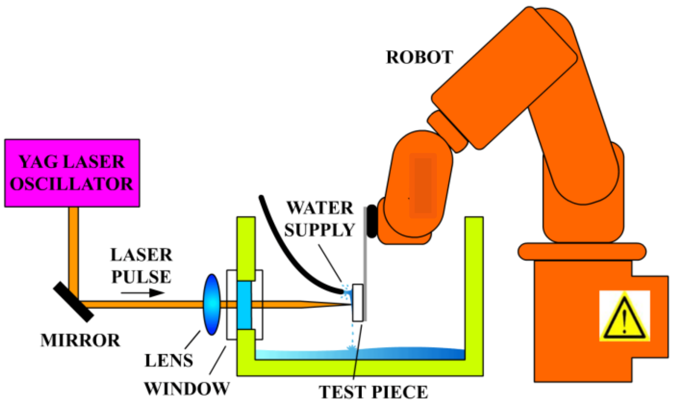


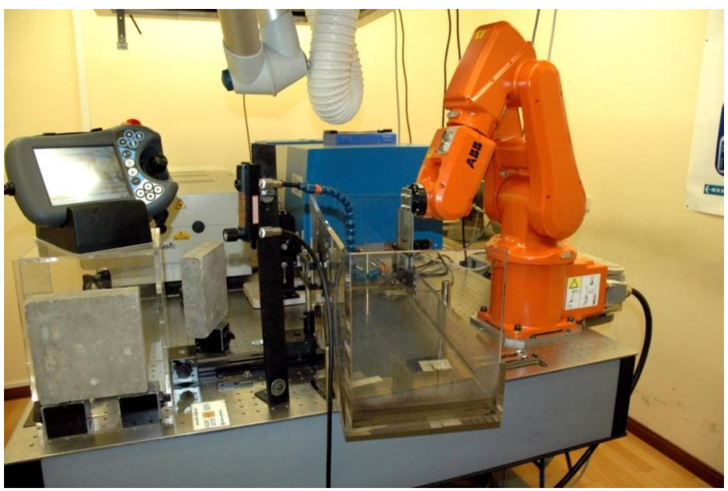


Young modulus (GPa)	**177.205**
Yield strength (MPa)	**355.410**
Ultimate yiled strength (MPa)	**633.608**

3. EXPERIMENTAL PROCEDURE

- **LSP parameters and annealing conditions**

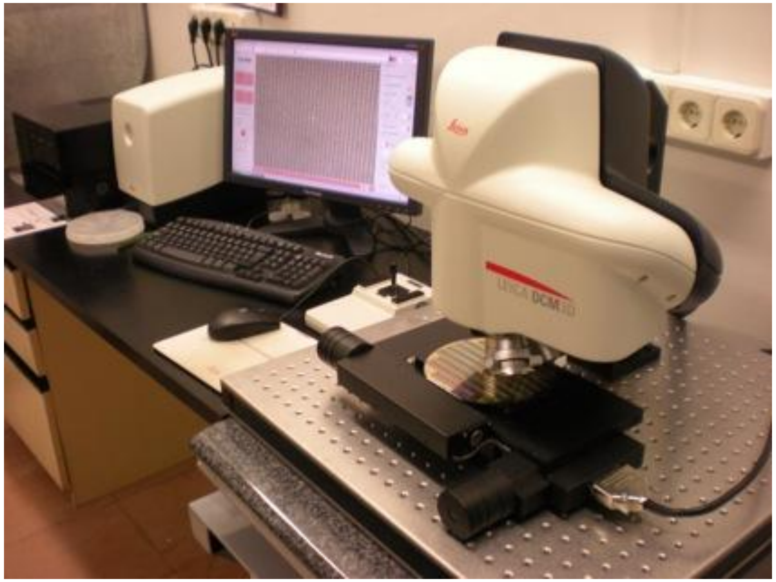




Process parameters	
Wavelength (nm)	1064
Frecuency (Hz)	10
Energy (J/pulse)	2.8
Pulse width (ns)	~ 9
Spot diameter (mm)	~ 1.5
Overlapping (pulses/cm^2)	900
	1600
Confining medium	Water jet
Absorbent coating	No

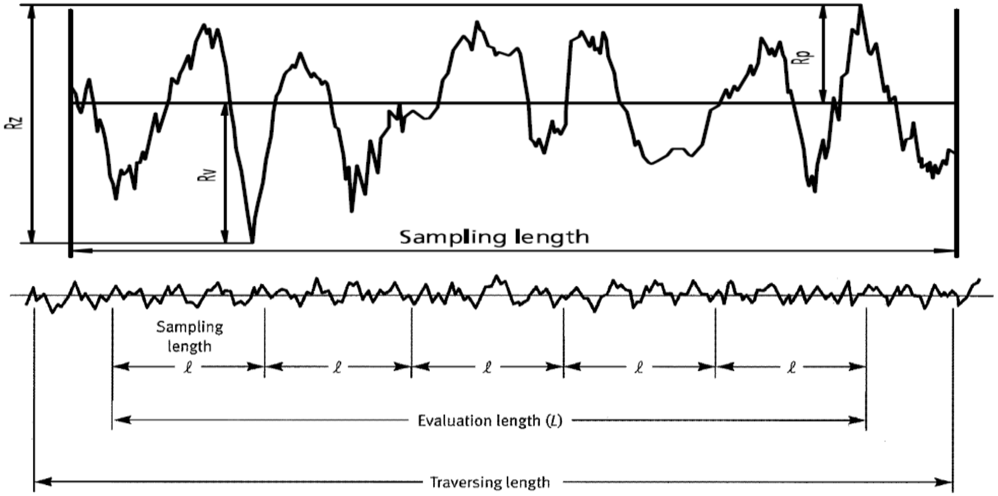
Thermal treatment	
Temperature (°C)	500
Time (hours)	8
Atmosphere	Air

- **Surface roughness measurement**
  - Topographic confocal microscopy



Confocal laser scanning microscope Leica DCM 3D

Measuring conditions (according to ISO 4287)	
λ_c (cut-off)	2.5
Evaluation length (mm)	12.5
Z-step (μm)	2

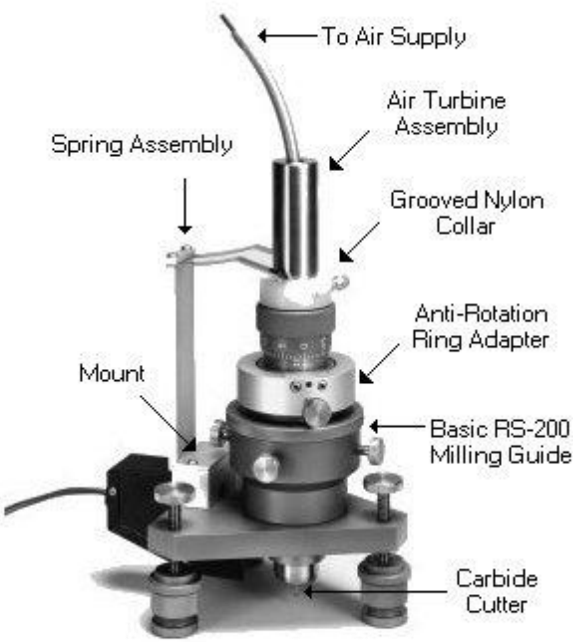


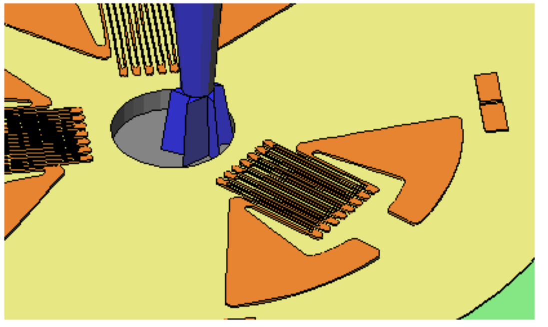
Parameter	Meaning	Formula
R_a	Arithmetic average of absolute values Z(x)	$R_a = \frac{1}{l}\int_0^l Z(x)\,dx$
R_v	Maximun valley depth	$R_v = \min Z_i(x)$

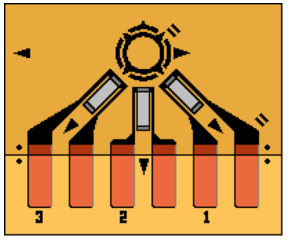
3. EXPERIMENTAL PROCEDURE

- **Residual stress measurement**

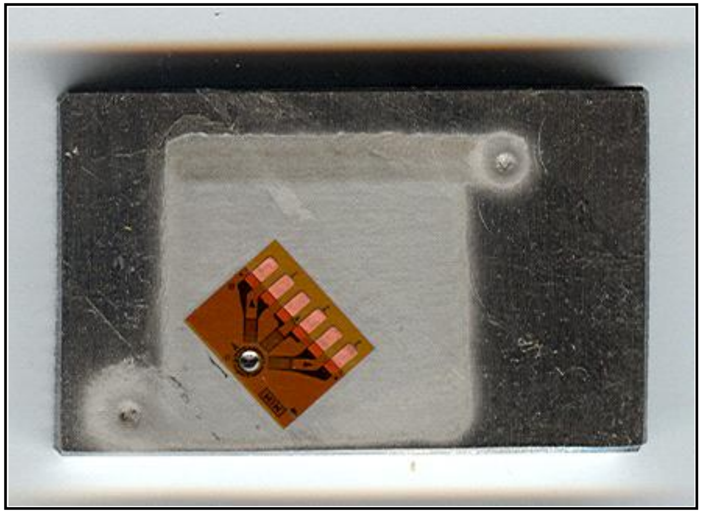
Residual Stresses Measurement Equipment (According to ASTM E837-08)





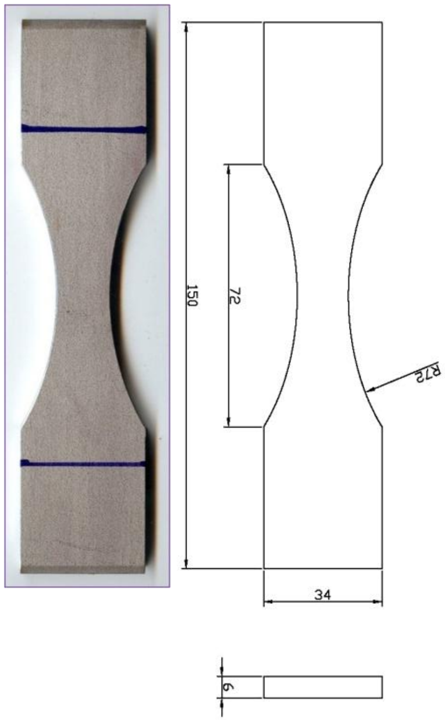


CEA-XX -062UM -120



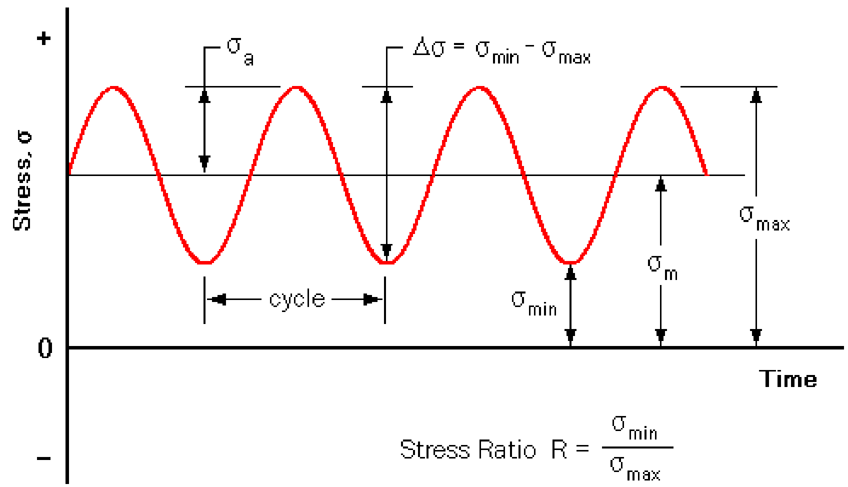
3. EXPERIMENTAL PROCEDURE

- **Fatigue test**



"Dog-Bone" shaped Specimens machined according ASTM E 466

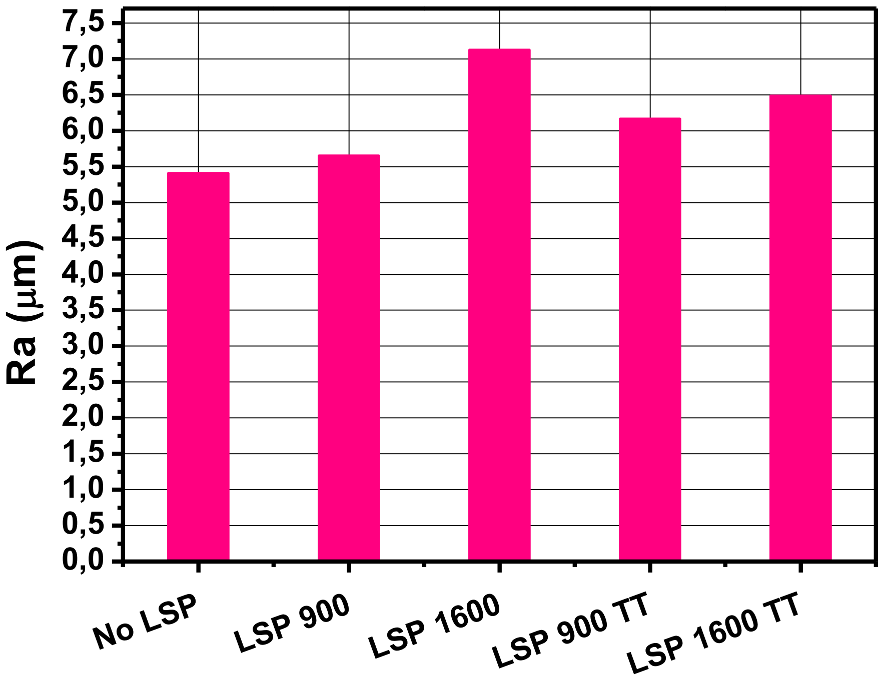
MTS 810 servo-hydraulic machine with load cell of 100 kN

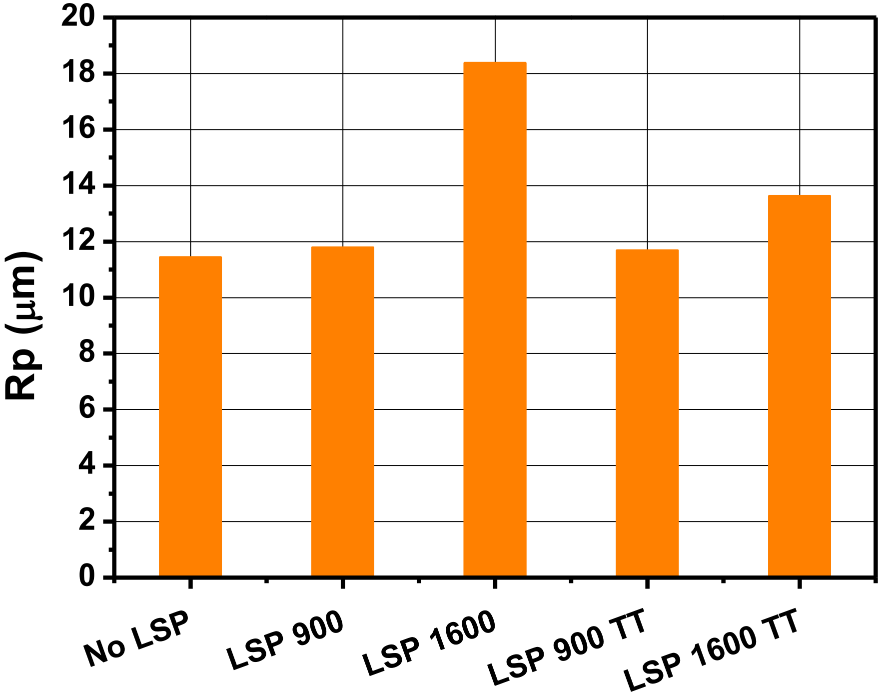


R=0.1
Frecuency=10 Hz
Room temperature

4. EXPERIMENTAL RESULTS

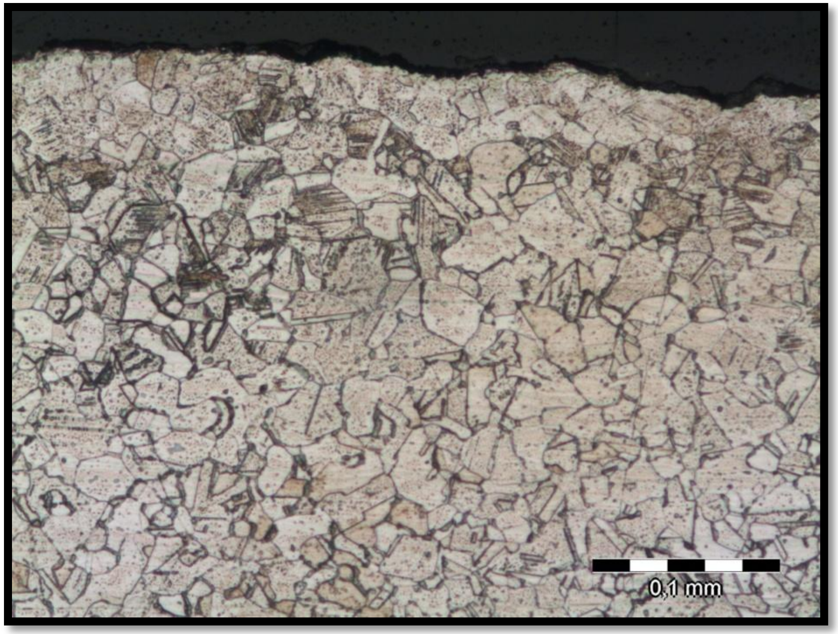
- **Surface roughness**



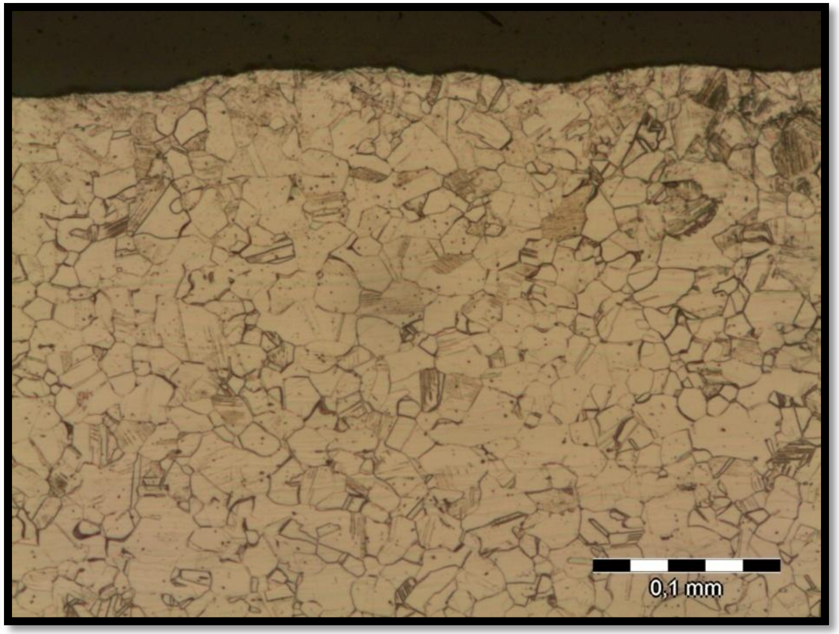


4. EXPERIMENTAL RESULTS

- **Microstructure**



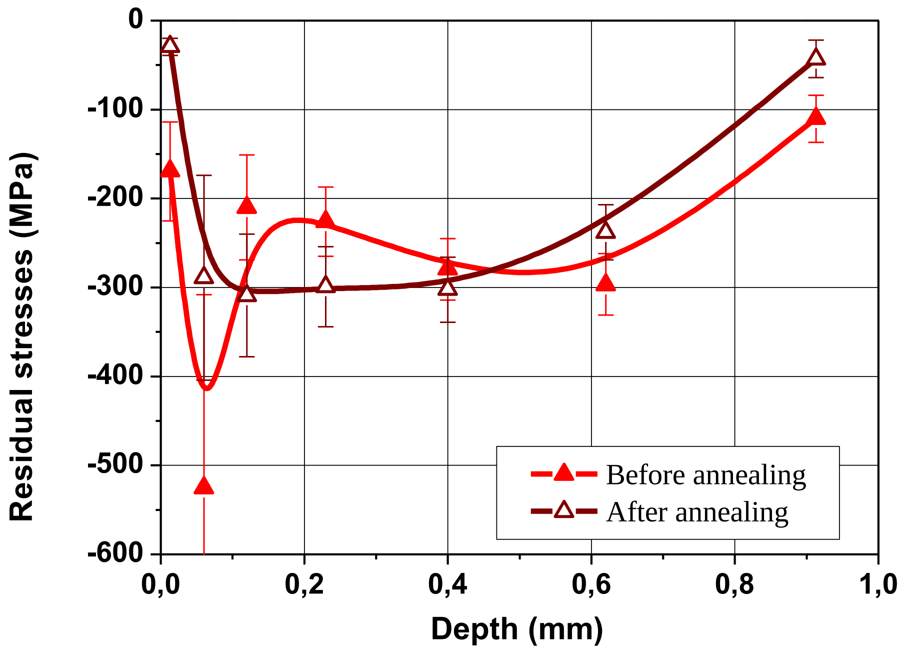
900 pulses/cm^2



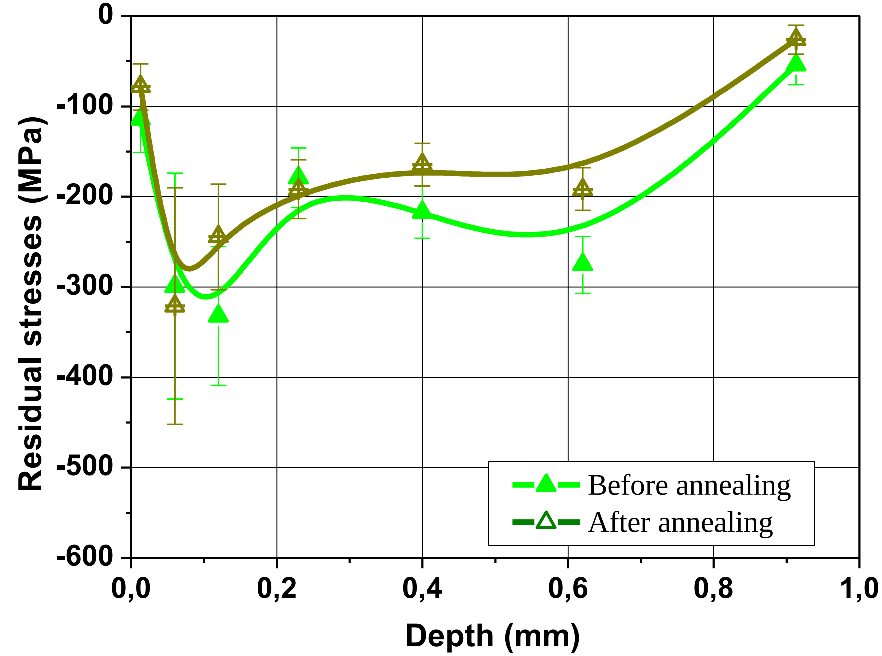
1600 pulses/cm^2

4. EXPERIMENTAL RESULTS

- <u>**Ressidual stresses**</u>



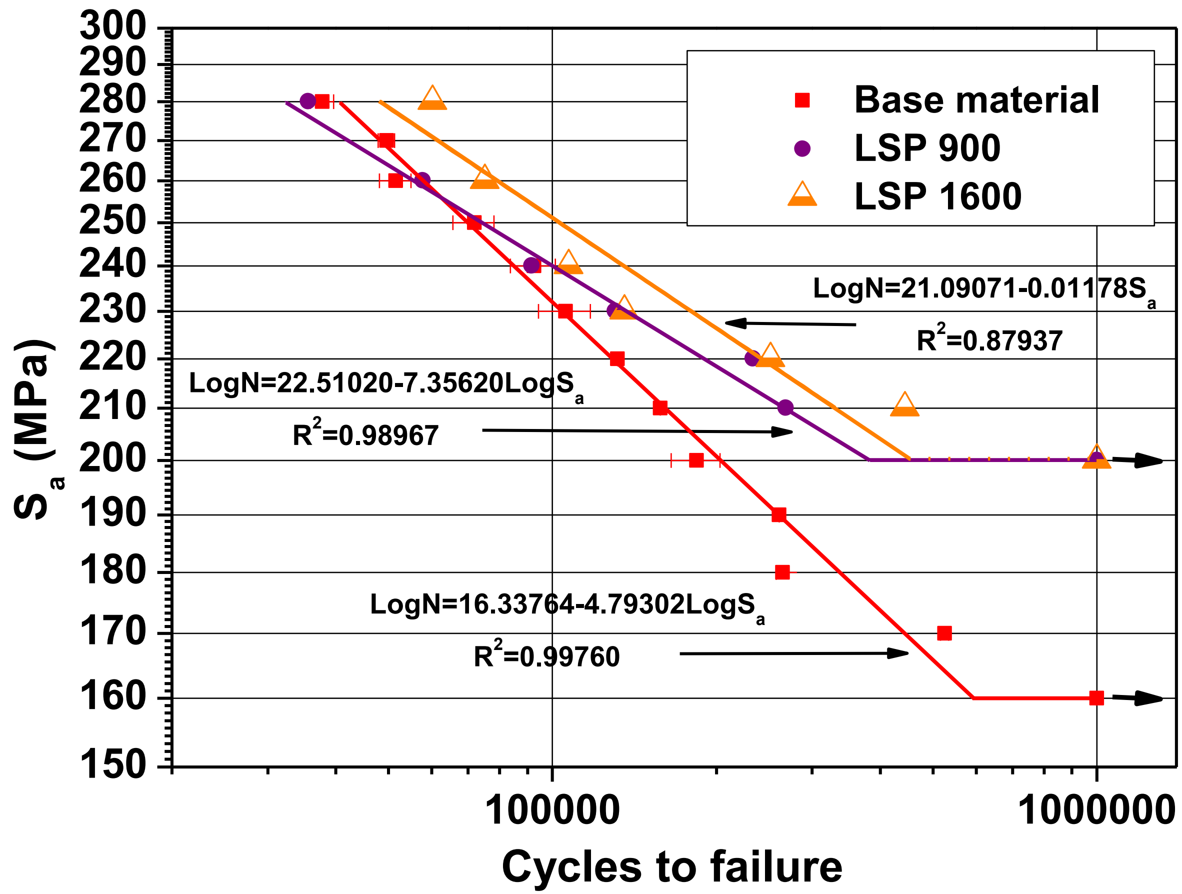
900 pul/cm^2



1600 pul/cm^2

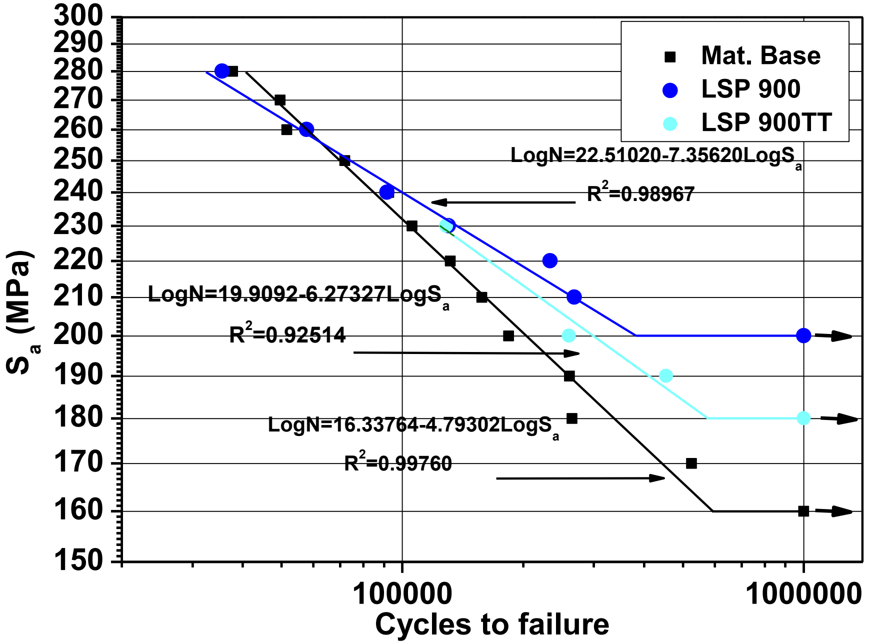
4. EXPERIMENTAL RESULTS

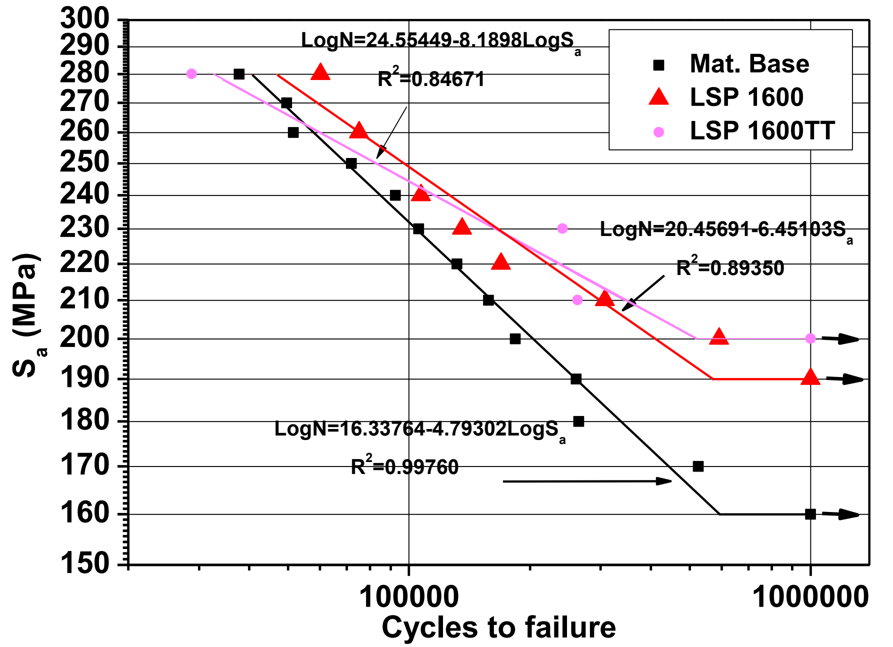
- **Fatigue life**



4. EXPERIMENTAL RESULTS

- **Fatigue life**





5. CONCLUDING REMARKS

- The effect of two representative LSP treatment intensities on the residual stresses and fatigue resistance has been analyzed for stainless steel 316L, in view of the excellent properties of this alloy in a significant number of industrial applications.

- These two laser peening intensities induce in the material a similar compressive stress distributions that achieve peak values between 300 and 400 MPa, and extend up to 1 mm from the surface.

- The significant residual stress fields induced by laser treatment improves the fatigue limit of stainless steel approximately 25 % in comparison with the unpeened material.

- The thermal treatment at 500 °C for 8 hours partially relieves the residual stresses, specially near the surface, but a significant compressive stress field remains (ranging from 200 to 300 MPa) between 100 and 600 microns below the surface. This can be due to the irreversible character of a significant proportion of mechanical dislocations induced by the LSP.

- The direct and desirable effect of this remaining RS field is a remarkable degree of permanence of the enhanced fatigue behaviour. Concretely, an improvement in fatigue limit of about 12% is maintained with regard to the pristine material.

ACKNOLEDGEMENT

The authors would like to thank the Spanish Ministry of Economy and Competitiveness (MINECO) for financial support under project MAT2012-37782.

mdiaz@upm.es

THANK YOU FOR YOUR ATTENTION